Proc. Indian Acad, Sci., C 1, No. 2, September 1978, pp. 205-220. © Printed in India.

The telecommand system

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MS received 28 April 1977; revised 25 December 1977

Abstract. The telecommand system plays an important role in the success of any satellite mission. This paper provides insights into the design, development and evolution of the *Aryabhata* telecommand system. The paper includes detailed specifications and performance of both the ground and onboard segments of the telecommand system.

Keywords. Command systems; coding; satellite telecommand.

1. Introduction

For effective control of different performance modes of the various satellite subsystems under all conditions, a highly efficient and responsive telecommand (TC) system is absolutely essential. Some of the important operations performed by the telecommand system include energising various subsystems, tape recorder operations, spin-up of satellite, phased operation of experiments, and switching over to redundant system during emergency/failure of main units. Since remote control through telecommand system is the mainstay for these operations to be reliably performed in the satellite in orbit, the system has to work with a high degree of reliability design-wise as well as hardware-wise.

This paper describes the system design, specifications and performance of both the ground and onboard segments of the telecommand system developed for the spacecraft *Aryabhata*.

2. Design objectives

The command system was designed to meet the following design requirements:
(i) high rejection of spurious signals,
(ii) minimum power consumption,
(iii) maximum reliability.

2.1. *High rejection of spurious signals*

To meet the requirement of high rejection of spurious signals, a coding scheme of 6-bit codes, where codes were limited to combinations of 3 Ones and 3 Zeros was selected. This code was designed to provide maximum protection against spurious triggering of command decoding circuitry while using a relatively narrow

bandwidth. This scheme provided 20 different command codes. This type of code had the property of rejecting all odd errors and 42% of even errors.

Originally the command frame consisted of a command word repeated 5 times. Due to the occurrence of spurious commands during tests the scheme of command comparison was incorporated. In this scheme, the onboard decoder had a memory and a bit by bit comparison facility. Command decoding was enabled only if two received commands were found to be identical bit by bit. With the introduction of the command comparison scheme the occurrence of spurious commands was eliminated.

As command codes consisting of 3 Ones and 3 Zeros were being used by other spacecraft, to prevent unwarranted execution of commands meant for some other satellite, an address was introduced. The address code word had a 'Hamming distance' of 3 with respect to any command code word. The decoding scheme was modified so that command comparison circuitry could work only after reception of a proper address code and the decoding circuitry was enabled only after reception of two identical command code words. To include the address, the command frame was restructured to a frame of two address words followed by four command code words.

2.2. *Minimum power consumption*

The onboard command system circuitry had extensively relied upon the use of complementary symmetry metal oxide semiconductor devices commonly known as COS/MOS. The COS/MOS devices offered the ultimate choice for low static power dissipation and extremely high noise immunity. These devices had the property of increasing dynamic power dissipation with the frequency of operation. However, dynamic power dissipation of COS/MOS was less than any other digital IC family for frequencies below 5 MHz. As dynamic power dissipation depended upon the capacitance and frequency product, care was taken to maximise values of resistors and minimise the values of capacitors, the efforts were limited only by the reliability considerations. The input biasing resistors also added up to extra power consumption and the values of these resistors were maximised to 1 megaohm to reduce this type of power drain. The biasing resistor could not be increased further without increasing the unreliability. By extensive use of medium scale integration (MSI) functions, the number of biasing resistors was reduced to the minimum, resulting in further reduction of dynamic power consumption. For switching functions, the use of latching relays was maximised. The non-latching relays were used only if functional and reliability considerations made such use indispensable.

These considerations resulted in a system design where both the static and dynamic power dissipation had been minimised without sacrificing reliability. The static power dissipation for the complete onboard command system had a negligible figure of 25 mW.

2.3. *Maximum reliability*

The onboard command system was designed and fabricated to provide maximum reliability. Selective use of redundancy was made to achieve maximum reliability

keeping extra circuitry to a minimum. Two subcarrier demodulators and two decoding sections were operating independently and in parallel. Cross coupling between the subcarrier demodulators and decoding sections increased the reliability since either subcarrier demodulator and either decoding section can fail simultaneously without affecting the command operation. Though full redundancy was adopted for the subcarrier demodulator and decoding section, only necessary line redundancy and duplication of circuitry for critical and vital functions were incorporated for command control units and energising unit.

The complete onboard system was arranged into six boxes, i.e., two decoders, three command control units and an energising unit. Both decoders were identical functionally, electrically and mechanically. Each decoder incorporated one subcarrier demodulator and one decoding section. The circuitry between command control units was partitioned in such a way as to minimise the interface between the different boxes resulting in a minimum number of interconnecting wires and increased reliability.

All the units were housed in milled aluminium boxes which provided rigid mechanical support, radiation and RF shielding for the electronics. Input/output points of each unit were separated out functionally into logic inputs, power supply inputs, interconnections, telemetering points, ground checkout and testing points and output lines and were terminated on separate connectors. Such functional separation of wires reduced the risk of any failure due to wiring harness. Independent testing of each box and step by step integration of boxes into the complete command system were made possible.

To match the power distribution with the redundancy of the decoders the telecommand system was fed through two failsafe units, one failsafe for each decoder. As the energising unit and the command control units should work even when one decoder fails the power outputs of both the failsafes were fed to the command control units and power switch-on unit through a power 'Or' gate.

Each failsafe was designed to supply current to one decoder and to all command control units and power switch-on unit. This scheme afforded protection against a short circuit in a decoder power line. However the command control unit power supply voltage was less than decoder supply voltages, by 600 mV. Diodes in series-parallel combination were introduced in the decoder supply line to guard the power supply line against diode failures.

Power supply harness and power distribution scheme were fully redundant. Each box was powered through two different connector pins and through two different paths. This ensured that breaking of one supply wire or a bad contact in power connector would not deprive any box of d.c. power supply.

The d.c. decoupling at the input 'Or' gates of command control units guarded against improper operation of command control units due to output failure of decoder in any one logic state. Resistive biasing of COS/MOS inputs, which were likely to float during fabrication, assembly or testing had removed any chance of COS/MOS failure during these stages due to incidence of stray charges.

3. System specifications

The technical specifications of the telecommand system are presented in table 1.

Table 1. Specifications of the telecommand system

Modulation	PDM/AM/AM
Carrier frequency	148·25 MHz
Carrier frequency stability	±0·002%
Carrier modulation	75%
Transmitter output power	1 kW
Ground antenna gain	15 dB
Subcarrier frequency	6·25 kHz
Subcarrier frequency stability	±0·002%
Subcarrier modulation	100%
Command frame length	48 bits (6 words)
Word length	8 bits (sync. 6 code bits, blank)
Bit period	72 cycles of 6·25 kHz subcarrier (11·52 m/s)
Bit rate	87 bits/s
Command frame structure	Two address words followed by four command execute words
Address code	111111 (six Ones)
Command execute code	3 Ones and 3 Zeros
Sync	54 cycles of subcarrier 'on'
One	36 cycles of subcarrier 'on'
Zero	18 cycles of subcarrier 'on'
Blank	Subcarrier 'off' for one bit period
No. of command execute codes	20
No. of direct commands	5
No. of shared commands	30
Total number of commands	35
Signal level at decoder input	2 V to 7 V peak to peak
Minimum S/NR ratio at the decoder input	13 db

4. System implementation

The onboard telecommand chain consists of a turnstile antenna, hybrid coupler, power divider, command receiver, command decoder and command control units. The antenna, hybrid coupler, power divider and command receivers are described elsewhere. The command decoder and the command control units will be described here. There are two identical decoders and four control units for command executions. Figure 1 shows the onboard command system block diagram.

The incoming signal is received by the antenna. The hybrid coupler isolates the outgoing telemetry signal from the incoming command signal. The output of the hybrid coupler is fed to the power divider which feeds the received command signal to the two receivers in equal proportions. The receiver detects and demodulates the received signal and makes the modulated subcarrier signal available as output.

The incoming signal from the receiver is fed to two active 2-pole bandpass filters (BPF) each having a centre frequency of 6·25 kHz and ± 7·5% bandwidth.

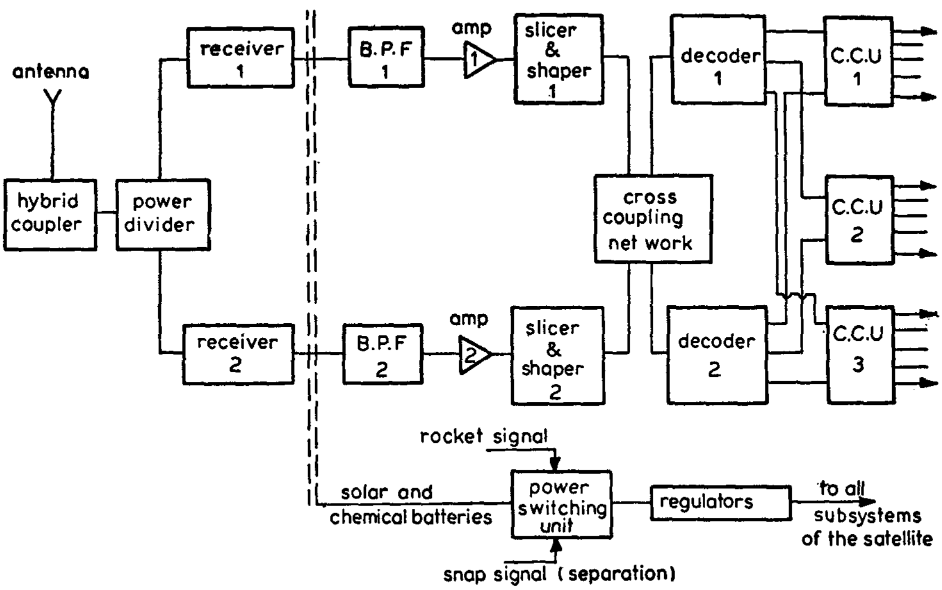

Figure 1. Onboard command system block diagram

This filter improves the S/N ratio by 16 dB. The BPF output is fed to the amplifier. The amplifier chosen has a voltage gain of 8.

The amplifier output is sliced at about 50% level to eliminate the base line noise. The high noise immunity property of COS/MOS devices is used for this purpose. The sliced output is shaped by two inverters to maintain the correct polarity. The output of the shaper consists of pulses at subcarrier frequency.

The shaper output is given to the cross-coupling network. It is a passive RC network where outputs from its preceding chains are given to two succeeding chains so that even if there is a failure in one of the preceding chains and another failure in any of the succeeding chains the link still works. As the passive RC network is used for the purpose of cross coupling, d.c. coupling between the preceding and succeeding chains is avoided to prevent failure mode effect on the succeeding chains.

The outputs of the cross-coupling network are fed to the two decoders. The outputs from both the decoders are given to the respective command control units for the command execution. The energising unit switches the raw power (solar/chemical battery) to the onboard regulators on receipt of the rocket signal or in case of rocket signal failure, the snap signal. The decoder and the command control units are discussed in more detail in the following sections.

4.1. *Decoder*

A block diagram of the decoder is shown in figure 2. The shaper output is fed to the clock pulse generator and the subcarrier demodulator through the cross-coupling network. This demodulator consists of COS/MOS gates and capacitor charging-discharging is used to strip out pulse duration modulation (PDM) waveform from subcarrier modulated signal. This gives the original PDM waveform, and at the same time the number of subcarrier pulses in each burst is counted by the 'bit

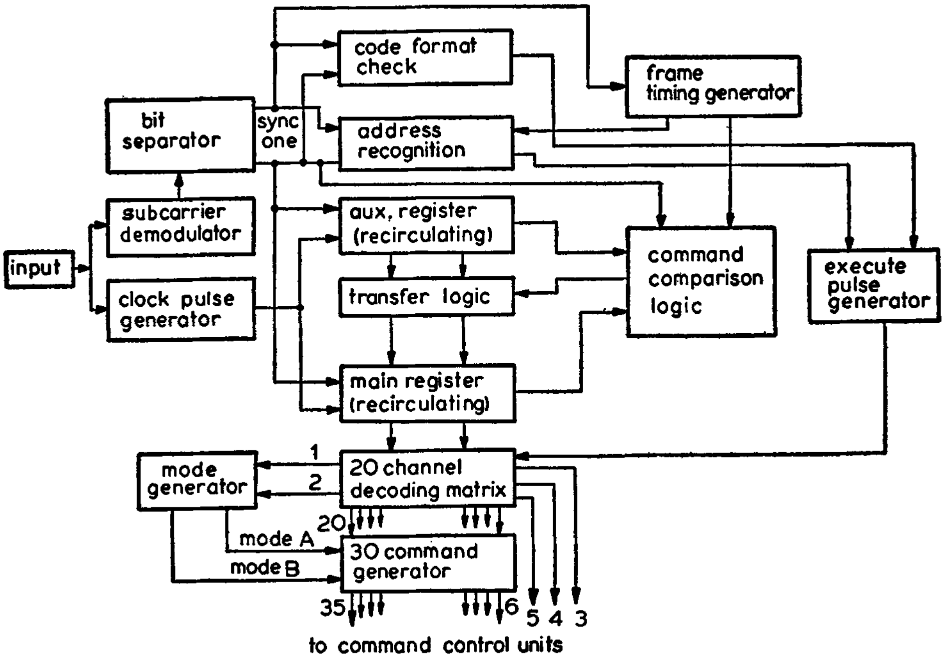

Figure 2. Decoder block diagram

separator ' to separate out Zero, One and Sync. Zero, One and Sync thus separated are made available on three different lines.

A Sync has to be obtained first before starting further processing. The Sync pulse thus separated is also used to trigger the ' frame timing generator ' which provides time slots for each of the word periods within a frame.

The number of Ones is counted in the ' code format check section '. The correct address word must contain 6 Ones. The address recognition section, upon reception of a correct address word enables a gate to generate the execute pulse.

The clock pulses for the shift register are derived from the trailing edges of the PDM bits. No clock pulse is generated if the PDM bit contains less than 9 subcarrier pulses. This minimises the effect of spurious spikes.

The first two address words are followed by four execute words. The first execute word is shifted into the six-stage main register. Only Ones are shifted into the register. The second execute word is shifted into the auxiliary register through selective steering circuit, while the contents of the main shift register are recirculated.

In both the registers, the serial information being recirculated is also fed into the command comparison logic where both the words are compared bit by bit. The third execute word is steered directly into the command comparison logic and is not stored anywhere. The third execute word is compared bit by bit with the first execute word stored in the main register and also with the second execute word stored in the auxiliary register. A ' coincidence pulse ' is generated on reception of any two identical execute words, by the command comparison logic (CCL) and it is fed to the execute pulse generator (EPG). In the case of execute words 1 and 2 being identical, the command stored in the main register is treated as valid command.

In the case of execute words 1 and 3 being identical, the desired command is in the main register. If, however, execute words 2 and 3 are identical, a 'transfer pulse' is generated which transfers the contents of the auxiliary register in parallel to the main register. This way the valid command is always available in the main register. Hence the decoding matrix is connected to the main register only.

An execute pulse is generated by the EPG upon reception of a coincidence pulse from CCL but only if enabling signals from the address recognition and code format check sections are present. The execute pulse enables the decoding matrix to decode the code. The output of the decoding matrix is available on 20 different lines, each corresponding to the particular execute code transmitted.

Output pulses of code nos. 3, 4 and 5 are used as direct commands. Pulses of code 1 and 2 are used as mode-A and mode-B commands in the mode generator to generate the mode-A and mode-B control signals for the 30-command generator.

The 30-command generator is a bank of 15 SPDT solid state switches. Depending upon the mode-A, mode-B control status, the pulses corresponding to any code from code 6 to code 20 can be routed to either of the lines. This way 15 codes are made to generate 30 commands. The 30 mode-controlled commands and the 3 direct commands are then fed to the command control units.

Table 2. Command allocation chart

Sl. No.	Command No.	Command Designation	Command function/operation
1.	1	Mode-A	Switches command decoding circuits to mode-A
2.	2	Mode-B	Switches command decoding circuits to mode-B
3.	3	Storage TM	(a) Switches the tape recorders to playback mode. (b) Switches telemetry to storage mode (c) Starts a timer which after 5 min switches telemetry to real time mode
4.	4	Real time TM	Switches telemetry to real time mode
5.	5	TR record	(a) Switches the tape recorders to record mode (b) Switches telemetry to real time mode
6.	6A	TR input Off	Disconnects the telemetry encoder output from tape recorder input
7.	7A	TR input On	Connects output of telemetry encoder to input of tape recorder
8.	8A	Encoder-2	Selects PCM and PCM complement signals from telemetry encoder No. 2
9.	9A	Encoder-1	Selects PCM and PCM complement signals from telemetry encoder No. 1
10.	10A	SCO-2	Connects output of subcarrier oscillator No. 2 from telemetry to input of telemetry transmitters
11.	11A	SCO-1	Connects output of subcarrier oscillator No. 1 from telemetry to input of telemetry transmitters.
12.	12A	Expts. Off	Switches Off d.c. power supply to Expt. 1, Expt. 2 and Expt. 3
13.	13A	Expt. 1 On	Switches On d.c. power supplies to Expt. 1
14.	14A	Expt. 2 On	Switches On d.c. power supplies to Expt. 2
15.	15A	Expt. 3 On	Switches On d.c. power supplies to Expt. 3

Table 2. Command allocation chart (*Contd.*)

Sl. No.	Command No.	Command Designation	Command function/operation
16.	17A	TR2 On	Connects the power and control circuits to tape recorder No. 2 and disconnects the same from tape recorder No. 1
17.	18A	TR 1 On	Connects the power and control circuits to tape recorder No. 1 and disconnects the same from tape recorder No. 2
18.	16A	TR's Off	Stops the tape recorder from recording or playing back if tape recorder has been in record or playback mode
19.	19A	TC test-2	Switches the TC test relay pole to 0 V on application of this command
20.	20A	TC test-1	Switches the TC test relay pole to + 9 V on application of this command
21.	6B	SS override	Removes inhibit signal for spin commands which is generated by sun sensor when spin rate of satellite is more than 20 rev/min
22.	7B	Spin arm	Makes spin circuits ready for receiving the spin command
23.	8B	Spin-3	Fires spin bottle No. 3
24.	9B	Spin-4	Fires spin bottle No. 4
25.	10B	Spin-5	Fires spin bottle No. 5
26.	11B	Spin-6	Fires spin bottle No. 6
27.	12B	Tx-2 On	(a) Switches On d.c. power supply to telemetry transmitter No. 2 (b) Switches Off d.c. power supply to telemetry transmitter No. 2 (c) Connects output of telemetry transmitter No. 2 to input of hybrid coupler
28.	13B	Tx-1 On	(a) Switches On d.c. power supply to telemetry transmitter No. 1 (b) Switches Off d.c. power supply to telemetry transmitter No. 2
29.	14B	PHA-2 On	Switches On pulse height analyser No. 2 for Expt. 1 and switches Off pulse height analyser No. 1
30.	15B	PHA-1 On	Switches On pulse height analyser No. 1 for Expt. No. 1 and switches Off pulse height analyser No. 2
31.	16B	Reserve	Spare command
32.	17B	PCM complement	Selects PCM complment data from tape recorder output channel No. 2 during TR playback for transmission of telemetry data.
33.	18B	PCM	Selects PCM data from tape recorder output channel No. 1 during TR playback for transmission of telemetry data
34.	19B	Tracking On	Connects tracking output from command receivers to input of telemetry transmitters
35.	20B	Tracking Off	Disconnects tracking output of command receivers from input of telemetry transmitter.

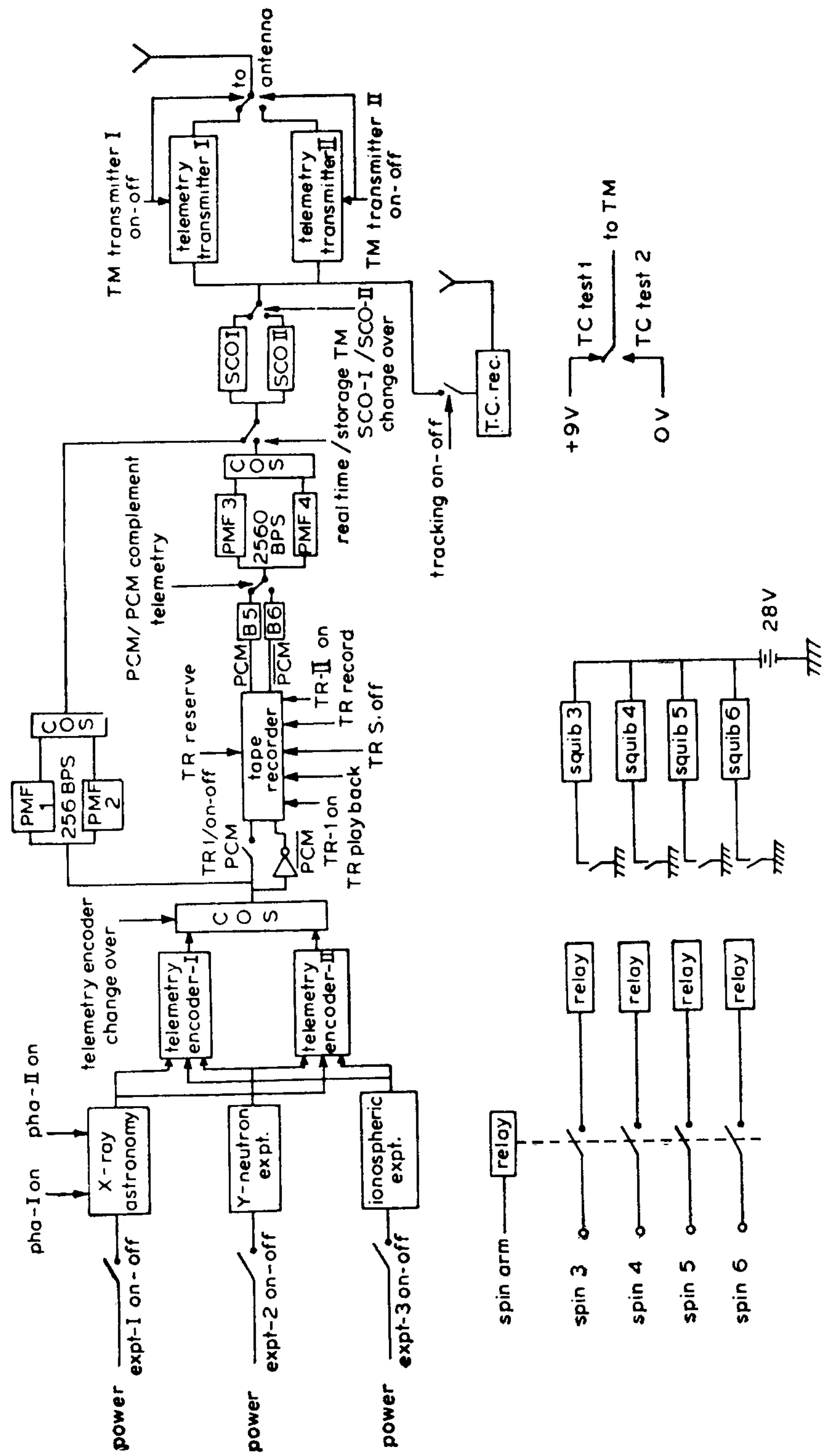

Figure 3. Onboard command operations

4.2. *Command control units*

The command control units execute the various commands. Table 2 gives the functions performed by the different commands and figure 3 shows the onboard command operations in a schematic way. The execution of different commands is allocated to these command control units.

4.2a. *Command control unit*-1

This unit executes the commands corresponding to the experiments and telemetry transmitters. On command, this unit switches On/Off the d.c. power supply inputs of the telemetry transmitter and also selects the r.f. output of the on-telemetry-transmitter for connection to the antenna through the hybrid coupler. On receipt of commands for the experiments, this unit switches On/Off d.c. power supply inputs of the respective experiment. This unit also provides the control signal for switching On/Off the pulse height analyser of the x-ray astronomy experiment.

4.2b. *Command control unit*-2

This unit executes the commands controlling the tape recorder (TR) and telemetry operations.

The storage telemetry and real time telemetry commands operate a solid state (COS/MOS) DPDT switch to select the direct data from telemetry or the played back data from the tape recorder to the transmitters through the sub-carrier oscillators (SCO). In addition, the storage telemetry command also puts the tape recorder into playback mode. The storage telemetry command also triggers the two onboard timers which, in turn, generate real time telemetry command after 5 min.

The TR record command puts the tape recorder into record mode. This command also operates the COS/MOS SPDT switch to connect the direct data from telemetry to transmitter through the subcarrier oscillators.

The TR 1 'On' command connects the power and control circuits to tape recorder No. 1.

The TR 2 'On' command connects the power and control circuits to the tape recorder No.2.

TR's Off command stops the tape recorder from recording if the tape recorder is in the record mode or from playing back if it is in playback mode.

The PCM and PCM complement commands operate a solid state (COS/MOS) DPDT switch to select the PCM data or PCM complement data for transmission during storage telemetry mode.

The SCO-1 and SCO-2 commands operate On and Off coils of a latching relay to select the output of SCO-1 or SCO-2 for connecting to the transmitters input for transmission of telemetry data.

The TC test-1 and TC test-2 commands operate On and Off coils of a latching relay to connect the TC test monitoring line to +9/OV.

4.2c. *Command control unit*-3 *and power switch on unit*

These two units work in conjunction to control the spin-up system and tracking

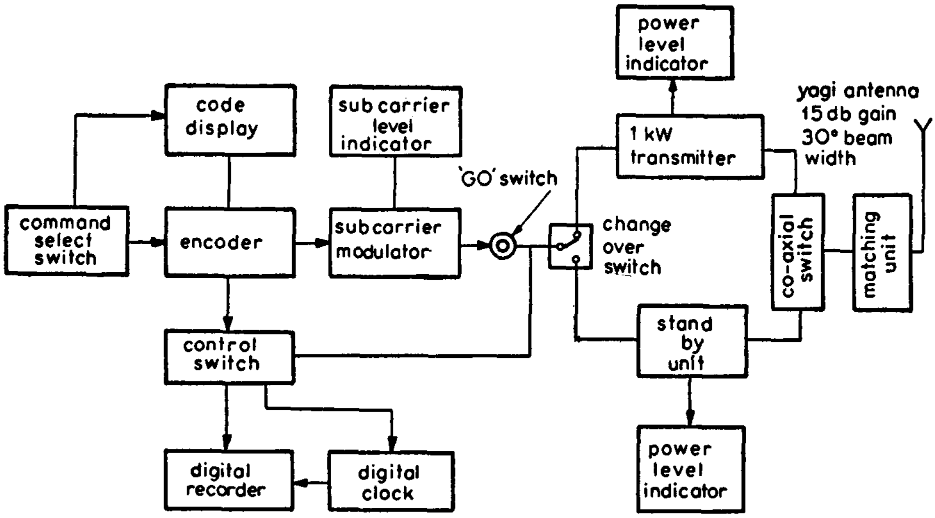

Figure 4. Telecommand ground station

system. These units are used for energising all satellite subsystems by the rocket signal. In case of a failure of the rocket signal, this unit energises the satellite by the signal generated at the time of the separation of the satellite from the rocket. With the help of the timers which are activated by the satellite power switch On, this unit fires the first spin bottle after 27 s and the second spin bottle after 89 s of the power switch On, to impart an initial spin rate of 90 rev/min to the satellite. The remaining four spin bottles are fired by this unit on reception of the proper spin command preceded by the Spin Arm Command. This unit also connects and disconnects the tracking signal to the telemetry transmitters.

This unit also incorporated the required circuitry to disconnect the spin-up system during ground checkout of the satellite at the launch pad.

5. Ground command system

The ground telecommand chain consists of a command encoder, a command transmitter and a command antenna. Figure 4 shows a block diagram of the telecommand ground station set-up. The command encoder and the transmitter are described in detail separately. The command code output of the command encoder is connected to a digital printer, which records the command sent and the time of transmission of the command. The command frame output of the command encoder is connected to the r.f. transmitter and the output of the transmitter is connected to the command antenna. To increase the reliability of the ground station, two encoders and two transmitters are provided at each station.

5.1. *Encoder*

The command encoder generates 20 different command frames corresponding to 20 different command execute codes. With the help of the front-panel-mounted

command selector switches any one of the twenty execute codes can be selected at a time. The command frame amplitude modulates the 6·25 kHz subcarrier to a depth of 100%.

A crystal-controlled master oscillator generates a 100 kHz master clock. This master clock is fed to a 4-stage binary divider which generates 6·25 kHz clock. The 6·25 kHz clock is fed to the subcarrier generator and timing waveform generator. The subcarrier generator is an active band pass filter with a centre frequency of 6·25 kHz. The output of this subcarrier generator is a 6·25 kHz sine wave.

These output pulses of 6·25 kHz are again divided in timing waveform generator by 18 to produce necessary basic timing signals which are again processed through two-stage binary counter to generate sync, one and zero pulses continuously on the three separate lines. These Sync, Ones and Zeros are combined in the proper order to generate the command frame. This command frame consists of two address words followed by four execute words.

This command frame is used as a control voltage of an analog switch for switching 6·25 kHz sine wave subcarrier to obtain PDM/AM signal at 100% modulation and is fed to VHF transmitter for transmission. Any desired command can be manually set with address in the command console and transmitted with a single depression of the ' GO ' switch provided in the console. Seven banks of 5 key piano switches are provided to select any one of the 35 commands. The code is first converted into a decimal form and then it is displayed on the front panel. Subcarrier level indicator and mode indicator are provided in the console along with the supply voltage and current indicators. The complete code can be printed along with the time of sending using any digital printer and the necessary interface required is housed in the console.

6. Link calculation

The output power of the command transmitter is fixed at 1 kW. The ground station cabling distance from the command transmitter to the command antenna is about 15 m. The cabling and other ground station losses are assumed to be about 2·5 dB and the ground telecommand antenna gain is about 15 dB. Since the range is constantly changing in the satellite system, the path loss is variable. For *Aryabhata* which is in a near circular orbit of 600 km, the minimum distance between the antenna and the satellite is 600 km and the maximum distance is 2800 km for zero degree elevation of the satellite. So, if the command has to be attempted at near zero degree elevation, the transmitter must have sufficient power for a range of 2800 km. The satellite antenna pattern has a dip of about 9 dB in certain directions. This aspect has also been taken into consideration in determining the transmitter power. The complete link calculation of the command chain, taking into account these considerations is given in table 3.

7. Command transmitter

The command transmitter is an AM transmitter which delivers an output power of 1 kW at the carrier frequency of 148·25 MHz. The transmitter can be modulated to

Table 3. Uplink estimation

Item	Gain/loss in dBs	Net power dB
1. Transmitter power		P_t
2. Ground station loss (due to cables connectors rotary joint and polarisation switch)	−2·5	
3. Ground antenna gain	15	
4. E. radiated power		$P_t+12{\cdot}5$
5. Tracking loss	−0·3	
6. Maximum propagation loss	−145	
7. Atmospheric attenuation	−0·5	
8. Fading margin	−5	
9. Polarisation	−3	
10. Power available at satellite antenna		$P_t-141{\cdot}3$
11. Onboard antenna gain	−9	
12. Hybrid loss	0·5	
13. Onboard connector and cable loss	−1·2	
14. Power split loss	−3·0	
15. Filter loss	−1·0	
16. Net power at Rx input		P_t-156

Assumed receiver sensitivity = −126 dBw
So, P_t − 156 dBw = −126 dBw
Or, P_t = 30 dBw = 1 kW
Receiver front end noise power = 148·5 dBw (assuming I.F. bandwidth of ±15 kHz,)
Input to the receiver = −126 dBw
Input S/N of the receiver = 22·5 dB
This S/N at the input of the receiver is sufficient to produce sufficiently good output S/N.

a depth of 80% without excessive distortion and the modulation frequency can be between 300 Hz and 10 kHz. The transmitter is essentially a class C plate modulated r.f. amplifier and uses a forced air cooled power stage. The carrier is generated at half the traffic frequency which is 74·125 MHz and then it is doubled and amplified to a level of 60 W to drive the final power amplifier.

For convenience of installation, operation and maintenance, the transmitter has been divided into four major blocks: (1) power amplifier; (2) low power unit; (3) modulation amplifier; (4) HV power supply and control circuit.

All these blocks have been fabricated into individual units and have been mounted in a 19 in. rack.

8. Tests and performance evaluation of the command system

The test and evaluation philosophy for the telecommand system incorporates rigorous testing at all levels of fabrication, handling and integration of the onboard telecommand system. To enable systematic testing, a Command Test Console was

developed and fabricated. This console was used to test individual command system boxes, the complete integrated onboard command system and the command system during various steps of integration with the spacecraft for all parameters and functional operations.

The test sequence for the onboard system included cold exposure at $-30°C$ for 6 hr, hot exposure at $+60°C$ for 6 hr, cold soak at $-10°C$ for 6 hr, hot soak at $+50°C$ for 6 hr, 5 g vibrations at 30 Hz to 60 Hz for 5 min and 20 shocks each of 20 g acceleration for 10 ms duration. These tests were followed by a thermovac test at $+50°C$ and 1×10^{-5} torr pressure for 24 hr and at $-10°C$ and 1×10^{-5} torr pressure for 24 hr.

8.1. *Special tests*

In addition to these environmental tests, the telecommand system along with the other systems was subjected to balloon test, helicopter test and aircraft test. The preprototype of the satellite was flown to a height of 35 km on a plastic balloon. Both the uplink and downlink were tested.

The helicopter test has been performed at SHAR with the preprototype and the prototype models of the satellite. This test has been used to qualify the telemetry and telecommand systems of the ground station and it also provided useful data of the simulated working of satellite during flight.

The aircraft test was carried out with the help of the prototype of the satellite at Bears Lake in Moscow for qualification of the telemetry and telecommand system of the Bears Lake ground station. The worst case link conditions were simulated and the actual operation of the satellite was checked under these conditions.

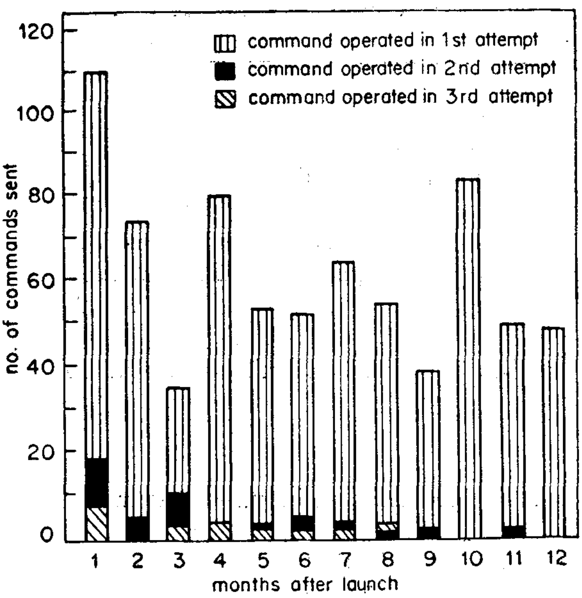

Figure 5. Histogram of command operations

Table 4. Summary of command operations till 10 April 1976

Command Number	Commands attempted	Commands executed	Commands failed to execute in one pass
1	149	148	1
2	140	138	2
3	115	112	3
4	3	3	—
5	5	5	—
6A	—	—	—
7A	1	1	—
8A	2	2	—
9A	3	3	—
10A	1	1	—
11A	1	1	—
12A	27	27	—
13A	10	10	—
14A	8	8	—
15A	7	7	—
16A	9	9	—
17A	6	6	—
18A	1	1	—
19A	19	18	1
20A	19	18	1
6B	2	2	—
7B	2	2	—
8B	1	1	—
9B	—	—	—
10B	—	—	—
11B	—	—	—
12B	1	1	—
13B	1	1	—
14B	9	9	—
15B	9	9	—
17B	1	1	—
18B	2	2	0
19B	132	129	3
20B	132	129	3
Total	818	804	14

9. In-orbit performance of the telecommand uplink

The telecommand uplink has operated successfully. Regular playback and tone range commands are being exercised from SHAR. Complete control of *Aryabhata* through commands has been achieved. The successful execution of more than 800 commands has justified the confidence placed in the command system. Table 4 gives the record of command operations. Figure 5 depicts the performance of command operations in a histogram form.

The performance of the uplink has been analysed for the behaviour of the onboard telecommand receiver and for the ability of telecommand decoding system to execute

the desired command without errors like failure of command system to effect a desired command and occurrence of spurious and false commands.

It has been observed that occasionally commands operated only after repeated transmission of commands. This phenomenon of the non-operation of the commands, in spite of the high signal levels can well be due to the highly secured design of the telecommand system. It incorporates a command comparison logic which automatically rejects any command, that has been impaired either by the channel or receiver noise. This logic ensures that only the proper command will be executed and false commands will never be executed. This clearly shows that the comparison logic rejected these commands which must have been impaired by the channel or receiver noise during the respective orbits.

The voice transmission experiment through *Aryabhata* was carried out using a 4 kHz carrier frequency modulated by voice frequency of 2 kHz. It is quite probable that the frequency band extended into 6·25 kHz region of the telecommand system and a certain amount of noise is bound to have been injected into the telecommand decoding system. But no spurious operation of command whatsoever has been observed during the voice testing over a number of passes. This confirms the excellent noise immunity of the telecommand decoder.

10. Conclusions

The operation of the command link during the orbital phase has conclusively proved the complete reliability of the *Aryabhata* command link and command system. The feasibility of the operation of commands even at very low elevation angles of the order of 5° has provided a greater operational manoeuvre over a single pass.

Acknowledgements

Besides the authors who worked on the *Aryabhata* telecommand system there were many other engineers who actively participated in the design, development and testing of the system. Special mention should be made of Messrs P K Shinde, B B Hakke, N N Singh, R D Bansiya, T S Narayanan, R Lakshminarasimhan and K Sunderesh who have contributed substantially to the content of this paper.